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TITLE: COUPLING OF CONDUCTIVE VIAS TO COMPLEX POWER-SIGNAL
SUBSTRUCTURES

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COUPLING OF CONDUCTIVE VIAS TO COMPLEX POWER-SIGNAL SUBSTRUCTURES

Background of the Invention

1. Technical Field

5 The present invention relates to an electrical laminate structure, and associated method of formation, having multilevel conductive vias that are electrically coupled to circuit features of the electrical laminate structure.

2. Related Art

10 A capability for increasing the yield of fabricated printed circuit structures would lower costs and improve profitability. Additionally, providing additional ways of electrically coupling circuit features of a printed circuit structure would improve design flexibility and efficiency.

 Accordingly, there is a need for increasing the yield of fabricated printed circuit structures. Additionally, there is a need for providing additional ways of electrically coupling circuit features of a printed circuit structure.

Summary of the Invention

15 The present invention provides a method of forming an electrical structure, comprising:
 forming a complex power-signal (CPS) substructure;
 testing an electrical performance of the CPS substructure to determine whether the CPS
20 substructure satisfies electrical performance acceptance requirements, wherein the testing
 includes testing for at least one of electrical integrity and electrical signal delay, and wherein the

testing for electrical integrity includes testing for at least one of an electrical short, an electrical open, and an erroneous impedance; and

if the testing determines that the CPS substructure satisfies the electrical performance acceptance requirements, then forming a dielectric-metallic (DM) laminate on a first external surface of the CPS substructure including forming a first multilevel conductive via through the DM laminate, wherein the DM laminate includes an alternating sequence of an equal number N of dielectric layers and metallic layers such that a first dielectric layer of the N dielectric layers is formed on the first external surface of the CPS substructure, wherein N is at least 2, and wherein the multilevel conductive via is electrically coupled to a first metal layer of the CPS substructure.

The present invention provides an electrical structure, comprising:

a complex power-signal (CPS) substructure;

a dielectric-metallic (DM) laminate that includes an alternating sequence of an equal number N of dielectric layers and metallic layers such that a first dielectric layer of the N dielectric layers is formed on a first external surface of the CPS substructure, wherein N is at least 2; and

a first multilevel conductive via through the DM laminate, wherein the first multilevel conductive via is electrically coupled to a first metal layer of the CPS substructure.

The present invention provides an electrical structure, comprising:

a complex power-signal (CPS) substructure that has passed an electrical performance acceptance test for at least one of an electrical integrity and electrical signal delay, wherein the test for electrical integrity includes a test for at least one of an electrical short, an electrical open, and an erroneous impedance;

a dielectric-metallic (DM) laminate that includes an alternating sequence of an equal number N of dielectric layers and metallic layers such that a first dielectric layer of the N dielectric layers is formed on a first external surface of the CPS substructure, wherein N is at least 2; and

5 a first multilevel conductive via through the DM laminate, wherein the first multilevel conductive via is electrically coupled to a first metal layer of the CPS substructure.

The present invention facilitates increasing the yield of fabricated electrical laminate structures (e.g., printed circuit structures). Additionally, the present invention provides additional ways of electrically coupling circuit features of an electrical laminate structure.

Brief Description of the Drawings

FIG. 1 depicts a front cross-sectional view of a single complex power-signal (CPS) substructure, in accordance with embodiments of the present invention.

FIG. 2 depicts a front cross-sectional view of a double complex power-signal (CPS) substructure, in accordance with embodiments of the present invention.

15 FIG. 3 depicts a dielectric-metallic (DM) laminate formed on the CPS substructure of FIG. 1, wherein the DM laminate includes simple, stacked and deep vias, in accordance with embodiments of the present invention.

FIG. 4 depicts a portion of the DM laminate of FIG. 3 with added simple-deep vias, in accordance with embodiments of the present invention.

20 FIG. 5 depicts a portion of the DM laminate of FIG. 3 with added stacked-deep vias, in accordance with embodiments of the present invention.

FIG. 6 depicts the CPS substructure of FIG. 1 with a first DM laminate formed on a first surface of the CPS substructure and a second DM laminate formed on a second surface of the CPS substructure, in accordance with embodiments of the present invention.

FIG. 7 depicts FIG. 6 with a conductive through hole formed through the first DM laminate, the CPS substructure, and the second DM laminate, in accordance with embodiments of the present invention.

FIG. 8 depicts a first DM laminate and a second DM laminate each coupled to a composite CPS substructure, in accordance with embodiments of the present invention.

Detailed Description of the Invention

FIG. 1 illustrates a front cross-sectional view of a single complex power-signal (CPS) substructure **10**, in accordance with embodiments of the present invention. The single CPS substructure **10** comprises: a power plane **12** sandwiched between dielectric layers **13** and **15**; and metal layers **14** and **16** on the dielectric layers **13** and **15**, respectively. A power plane is a continuous electrically conductive metal sheet (e.g., a copper sheet) with one or more holes therein (e.g., the hole **5** in the power plane **12**). The dielectric layers **13** and **15** comprise a dielectric material **17** such as an organic dielectric material (e.g., polytetrafluoroethylene (PTFE), epoxy-fiberglass, polyimide epoxy, etc.). The metal layers **14** and **16** may each be a signal plane or a power plane. A signal plane comprises one or more electrically conductive circuit lines (e.g., copper circuit lines or copper-plated circuit lines). The metal layer **14** includes metallizations **21**, **31**, **28**, and **29**. The metal layer **16** includes metallizations **22**, **30**, and **32**.

Definitionally, a single complex power-signal substructure is a multilayered laminate

having a complex power-signal (i.e., within an interior portion of the multilayered laminate), and alternating dielectric and metal layers on each of two opposing surfaces of the complex power-signal starting with a first dielectric layer at the power plane surface and ending with a metal layer furthest from the power plane surface.

5 The single CPS substructure **10** also includes electrically conductive vias **36**, **24**, and **26**. The conductive via **36** is a via that is filled with electrically conductive metal (e.g., copper), and conductively contacts the power plane **12**. The conductive via **24** is a through via that has an electrically conductive metal (e.g., copper) plating **27**. The space **25** that is interior to the plating **27** may be void, filled with electrically insulative material, or filled with electrically conductive material. The conductive via **24** electrically couples the metallizations **31** and **30**, respectively, on the metal layers **14** and **16**. The conductive via **26** is a through via that is filled with an electrically conductive metal (e.g., copper), and electrically couples the metallizations **28** and **32**, respectively, on the metal layers **14** and **16**. The conductive vias **36**, **24**, and **26** are representative of a variety of conducting vias that may be formed in the single CPS **10**.

10 Definitionally, a “conductive via” or a “conducting via” may be either a filled via such as the vias **36** and **26**, or a plated via such as the via **24**. Any plated via in any of FIGS. 1-8 described herein may be plated with any suitable conductive material as would be known to one of ordinary skill in the art, including, *inter alia*, plated copper. Any filled via in any of FIGS. 1-8 described herein may be filled with any suitable conductive material as would be known to one of ordinary skill in the art, including, *inter alia*, copper or screened electrically conductive holefill material (e.g., electrically conductive silver paste).

20 The single CPS substructure **10** may be formed by, *inter alia*, by: providing the metal

sheet 18 and forming one or more holes in the metal sheet 18; forming the dielectric layers 13 and 15 on opposite sides of the metal sheet 18; forming the vias 36, 24, and 26 (such as by, *inter alia*, laser ablation, mechanical drilling, and plasma etch); filling the vias 36 and 26 with electrically conductive metal; forming the plating 27 on sidewalls of the through via 24 followed by filling the via 24 with the electrically insulative material 25; and forming the metal layers 14 and 16 on the dielectric layers 13 and 15, respectively.

FIG. 2 depicts a front cross-sectional view of a double complex power-signal (CPS) substructure 70, in accordance with embodiments of the present invention. The double CPS substructure 70 of FIG. 2 differs from the single CPS substructure 10 of FIG 1 in that the power plane 12 of FIG. 1 is replaced by the power planes 33 and 35 (with interfacing dielectric layer 34) in FIG. 2. The double CPS substructure 70 may be formed by, *inter alia*, compressing the dielectric layer 34 between the power planes 33 and 35, followed by the same procedure that was described *supra* for forming the single CPS substructure 10 of FIG. 1.

The single CPS substructure 10 of FIG 1 and double CPS substructure 70 of FIG. 2 are each an example of a CPS substructure. Generally a L-CPS substructure has L complex power-signals separated from each other (or from one another) by dielectric layering if $L \geq 2$. The single CPS substructure 10 is a 1-CPS substructure, and the double CPS substructure 70 is a 2-CPS substructure.

After formation of a CPS substructure (e.g., the single CPS substructure 10 or the double CPS substructure 70) and prior to additional processing in which one or more dielectric metallic laminates are formed on the CPS substructure as will be described *infra*, the CPS substructure is tested as to its electrical performance to determine whether the CPS substructure has passed such

tests or testing (i.e., to determine whether the CPS substructure satisfies electrical performance acceptance requirements). Such electrical performance acceptance requirements may be predetermined (i.e., determined in advance prior to the testing). Such electrical performance testing may include testing for at least one of electrical integrity and electrical signal delay.

5 Testing for electrical integrity includes testing for at least one of electrical shorts, electrical opens, and erroneous impedances (i.e., impedances that are outside of tolerance limits of expected impedances, for impedances along selected circuit paths through and/or on the CPS substructure). Testing for electrical signal delay includes measuring a time of flight of a signal passed into the CPS substructure and reflected back, for detecting such faults as an undesired dielectric constant. An advantage of performing such electrical performance testing on the CPS substructure prior to further processing is that such error detection in the CPS substructure involves, at worst, discarding the defective CPS substructure at this early stage in the processing, which reduces costs and improves yields.

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15 If the aforementioned testing determines that the CPS substructure satisfies the electrical performance acceptance requirements, then further processing may proceed as in FIG. 3. If the testing determines, however, that the CPS substructure does not satisfy the electrical performance acceptance requirements (i.e., the CPS substructure is defective), then a new CPS substructure may be formed and such new CPS substructure may replace the defective CPS substructure. Then, the aforementioned testing may be again performed on the CPS substructure so replaced.

20 In accordance with embodiments of the present invention, FIG. 3 depicts an electrical structure **90**, comprising a dielectric-metallic (DM) laminate **40** formed on the single CPS substructure **10** of FIG. 1. In FIG. 3, forming the DM laminate **40** comprises: forming a

dielectric layer 41 on an external surface 8 of the CPS substructure 10; forming a metallic layer 42 on the dielectric layer 41; forming a dielectric layer 43 on the metallic layer 42, and forming a terminating metallic layer 44 on the dielectric layer 43. The dielectric layers 41 and 43 may each include a dielectric material such as an organic dielectric material (e.g., polytetrafluoroethylene (PTFE), epoxy-fiberglass, polyimide epoxy, etc.), and the dielectric material in the dielectric layers 41 and 43 may be the same dielectric material or different dielectric materials. The metallic layers 42 and 44 may each include a signal plane or a power plane, made of an electrically conductive metal such as, *inter alia*, copper. The metallic layer 42 includes a metallization 46. The metallic layer 44 includes metallizations 48, 49, and 59.

Generally, A DM laminate on a CPS substructure includes an alternating sequence of an equal number N of dielectric layers and metallic layers such that a first dielectric layer of the N dielectric layers is formed on an external surface of the CPS substructure, wherein N is at least 2. In FIG. 3, N=2 for the DM laminate 40.

Various conductive blind vias may be formed in the DM laminate 40 as shown. The DM laminate 40 includes a simple blind via ("simple via") 53, deep blind vias ("deep vias") 54, 55, 56, and 57, and a stacked blind via ("stacked via") 58. A simple via is formed by a via-forming operation through one dielectric layer. A deep via is formed by a via-forming operation through two or more dielectric layers. A stacked via passes through two or more layers, but is formed in each such layer individually, one layer at a time. A steep via has smooth sidewalls, while a stacked blind via has discontinuities in sidewall smoothness at layer interfaces, as shown in FIG. 3. Each blind via shown in FIG. 3 may be formed by a method such as, *inter alia*, laser ablation, mechanical drilling, and plasma etch. While the via 54 has an electrically conductive plating 83

(e.g., copper plating) on its sidewalls with insulative fill **84**, the vias **54**, **55**, **56**, **57**, and **58** are each filled with conductive material such as copper or screened electrically conductive holefill material (e.g., electrically conductive silver paste). Generally, a via in the DM laminate **40** may be of the conductively plated type or of the conductively filled type.

5 Variants of steep via, called “simple-deep vias” and “stacked-deep vias”, are shown in FIGS. 4 and 5, respectively, in accordance with embodiments of the present invention. FIG. 4 shows an electrical structure **92**, comprising a DM laminate **68** formed on the external surface **8** of the CPS substructure **10**. The DM laminate **68** has three dielectric layers, namely the dielectric layers **61**, **62**, and **63**, and three metallic layers (not shown for simplicity, but analogous to the metallic layers **42** and **44** in FIG. 3). The DM laminate **68** includes a simple-deep via **65** and a simple-deep via **66**. A simple-deep via is a combination of a simple via and a deep via in electrically conductive contact as shown. The simple-deep vias **65** and **66** may each be formed by a method such as, *inter alia*, laser ablation, mechanical drilling, and plasma etch, of the simple via and deep via components of the simple-deep via.

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20 FIG. 5 shows an electrical structure **94**, comprising a DM laminate **78** formed on the external surface **8** of the CPS substructure **10**. The DM laminate **78** has four dielectric layers, namely the dielectric layers **71**, **72**, **73**, and **74**, and four metallic layers (not shown for simplicity, but analogous to the metallic layers **42** and **44** in FIG. 3). The DM laminate **78** includes a stack-deep via **75** and a stacked-deep via **76**. A stacked-deep via is a combination of a stacked via and a deep via in electrically conductive contact as shown. The stacked-deep vias **75** and **76** may each be formed by a method such as, *inter alia*, laser ablation, mechanical drilling, and plasma etch, of the simple via and deep via components of the simple-deep via.

Definitionally, a “multilevel via” is a conductive via that passes through two or more dielectric layers. Thus a simple via is not a multilevel via, and the following types of vias are multilevel vias: a deep via, a stacked via, a simple-deep via, and a stacked-deep via.

Returning to FIG. 3, the simple via **53** is in electrically conductive contact with the metallization **46** of the metallic layer **42** that is interior to the DM laminate **40**. The multilevel vias **54**, **55**, **56**, **57**, and **58** each pass through the total thickness of the DM laminate **40** and each is electrically coupled to a metal layer of the CPS substructure **10**. In particular, the via **54** is electrically coupled to the metallization **21** at the metal layer **14** of the CPS substructure **10**. The via **55** is electrically coupled to the metallization **18** at the power plane **12** of the CPS substructure **10**. The via **55** is electrically coupled to the metallization **18** through electrical coupling between the via **55** and the conducting via **36**, wherein the conducting via **36** terminates at the metallization **18** and extends through less than the total thickness of the CPS substructure **10**. The via **56** is electrically coupled to the metallization **30** at the metal layer **16** of the CPS substructure **10**, through electrical coupling between the via **56** and the conducting via **24**, wherein the conducting via **24** terminates at the metallization **30** at the surface **9** and extends through the total thickness of the CPS substructure **10**. The via **57** is electrically coupled to the metallization **32** at the metal layer **16** of the CPS substructure **10**, through electrical coupling between the via **57** and the conducting via **26**, wherein the conducting via **26** terminates at the metallization **32** at the surface **9** and extends through the total thickness of the CPS substructure **10**. The via **58** is electrically coupled to the metallization **29** at the metal layer **14** of the CPS substructure **10**.

Each dielectric layer and adjacent (above) metallic layer of the DM substructure **40** may

be formed individually on the electrical structure below, followed by examining (i.e., testing) the electrical performance of the electrical structure 90 formed thus far to determine whether the electrical structure 90 satisfies electrical performance acceptance requirements. Such electrical performance acceptance requirements may be predetermined. Such electrical performance examining may include examining for at least one of electrical integrity and electrical signal delay. Examining for electrical integrity includes examining for at least one of electrical shorts, electrical opens, and erroneous impedances. Examining for electrical signal delay includes measuring a time of flight of a signal passed into the electrical structure 90 and reflected back, for detecting such faults as an undesired dielectric constant. If the examining determines that the electrical structure satisfies the electrical performance acceptance requirements, then the process of forming the DM laminate 40 is continued if less than a maximum of N metallic layers have been formed (N=2 in FIG. 3), but if N metallic layers have been formed then the process of forming the DM laminate ends. If the examining determines, however, that the electrical structure 90 does not pass the electrical performance acceptance requirements, then the process of forming the DM laminate may be discontinued.

The DM laminate 40 on the CPS substructure 10 may represent, *inter alia*, a chip carrier or a printed circuit board. Accordingly, the electrical structure 90 may also include an electronic assembly 50 (e.g., a semiconductor chip) that is electrically coupled to the DM laminate 40 at the metallization 49 (which may include an electrically conductive pad) by use of a conductive connector 51. The conductive connector 51 may include, *inter alia*, a controlled collapse chip connection (C4) solder ball. If the DM laminate 40 represents a chip carrier, then the electronic assembly 50 may represent a semiconductor chip. If the DM laminate 40 represents a printed

circuit board, the electronic assembly 50 may represent a chip carrier or a semiconductor chip.

FIG. 6 depicts an electrical structure 96, based on the electrical structure 90 of FIG. 3 with an added DM laminate 39 formed thereon. In FIG. 6, the electrical structure 96 includes: the DM laminate 40 on the exterior surface 8 of the CPS substructure 10; and the DM laminate 39 on the exterior surface 9 of the CPS substructure 10, wherein the surfaces 8 and 9 are opposite surfaces of the CPS substructure 10. In FIG. 6, a metal layer 116 has replaced the metal layer 16 of FIG. 3. In FIG. 6, the DM laminate 39 has the same properties and characteristics as the DM laminate 40 described *supra*. Thus in FIG. 6, the DM laminates 39 and 40 have the same structural features and capabilities, the same functionality, and may be subject to the same electrical performance testing.

Generally, the DM laminate 40 may include N dielectric layers, and the DM laminate 39 may include M dielectric layers, wherein $M=N$ and $M \neq N$ are each within the scope of the present invention. The DM laminate 39 may be formed on the CPS substructure 10 by the same methods described *supra* for forming as the DM laminate 40 on the CPS substructure 10. If $M=N$, then the DM laminate 40 and the DM laminate 39 may be formed symmetrically with respect to the CPS substructure 40; i.e., each dielectric layer (and adjacent metallic layer above) of the DM laminate 40 may be formed concurrent with formation of a corresponding dielectric layer (and adjacent metallic layer above) of the DM laminate 39 in generating the electrical structure 96.

FIG. 7 depicts the electrical structure 96 FIG. 6 with a conductive through hole 80 replacing in FIG. 6: the deep blind via 57 of the DM laminate 40, the conducting via 26 of the CPS substructure 10, the deep blind via 157 of the DM laminate 39, the metallization 28 of the metal layer 14 in the CPS substructure 10, and the metallization 87 of the metal layer 116 in the

CPS substructure 10. The conductive through hole 80 passes through the total extent (i.e., thickness) of the electrical structure 96 as shown. Thus, the conductive through hole 80 may be used to electrically couple the exterior surface 6 of the DM laminate 40 with the exterior surface 7 of the DM laminate 39.

FIG. 8 depicts an electrical structure 98, which comprises the electrical structure 96 of FIG. 7 with an added CPS substructure 11 formed between the CPS substructure 10 and the DM laminate 39. In FIG. 8, a composite CPS substructure 86 is formed by coupling (e.g., laminating) the surface 9 of the CPS substructure 10 to a surface 89 of an interfacing dielectric layer 85, and coupling a surface 108 of the CPS substructure 11 to a surface 88 of the interfacing dielectric layer 85. The DM laminate 40 is formed on the CPS substructure 10 as has been described *supra*. The DM laminate 39 is formed on the CPS substructure 11 in the same manner as the DM laminate 40 is formed on the CPS substructure 10. A conductive through hole 180 in FIG. 8 replaces the conductive through hole 80 in FIG. 7. The conductive through hole 180 in FIG. 8 has the same or analogous functionality as the conductive through hole 80 in FIG. 7. In FIGS. 7 and 8, the DM laminates 39 and 40 have the same structural features and capabilities, the same functionality, may be performed in the same manner, and may be subject to the same electrical performance testing. In FIGS. 7 and 8, the CPS substructures 11 and 10 have the same structural features and capabilities, the same functionality, may be performed in the same manner, and may be subject to the same electrical performance testing. Such electrical performance testing may be independently performed on the CPS substructures 11 and 10.

While embodiments of the present invention have been described herein for purposes of illustration, many modifications and changes will become apparent to those skilled in the art.

Accordingly, the appended claims are intended to encompass all such modifications and changes as fall within the true spirit and scope of this invention.

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